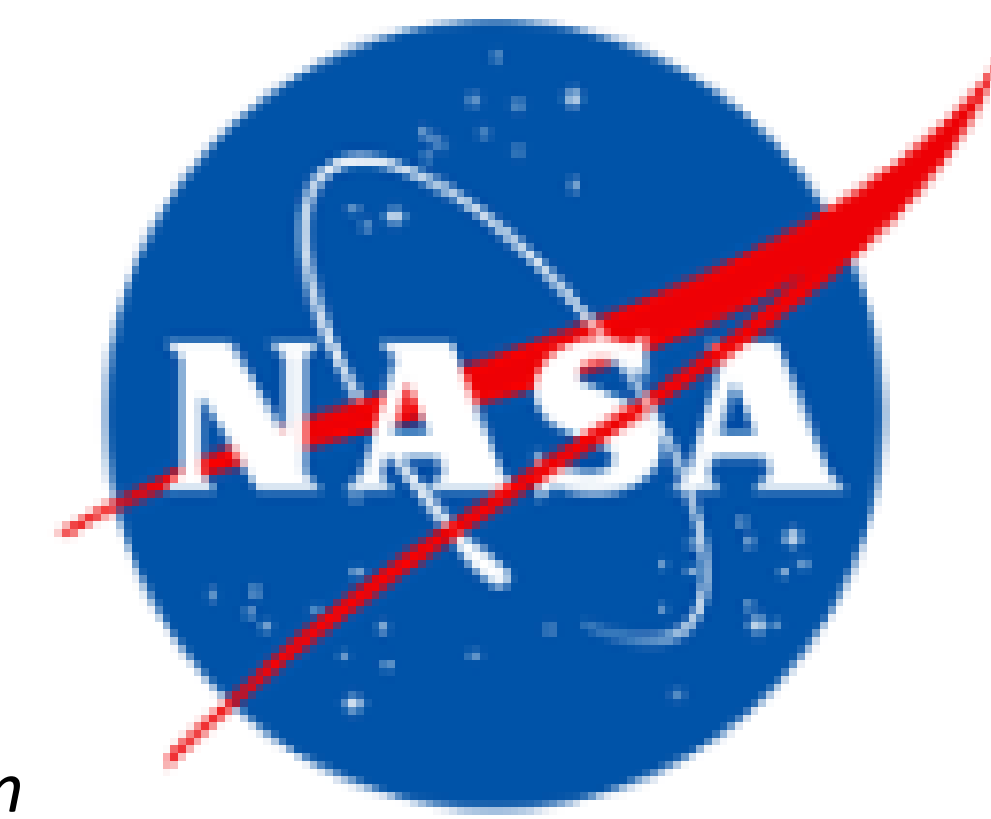


# A Tool for the Automated Collection of Space Utilization Data: *Three Dimensional Space Utilization Monitor*



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## Background and Introduction

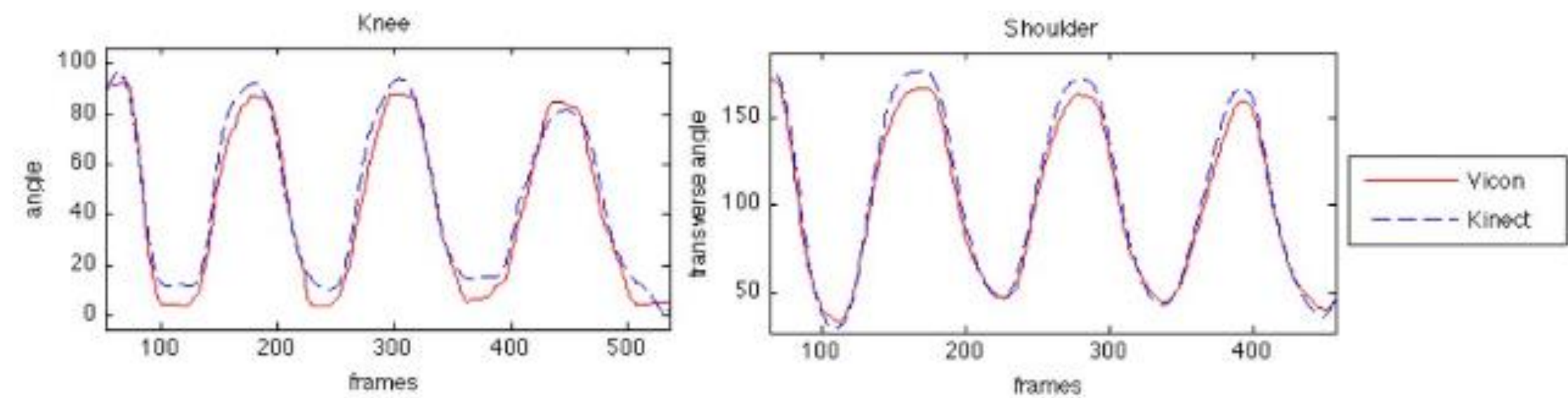
- Space Human Factors and Habitability (SHFH) Element within the Human Research Program (HRP) and the Behavioral Health and Performance (BHP) Element are conducting research regarding Net Habitable Volume (NHV), the internal volume within a spacecraft or habitat that is available to crew for required activities, as well as layout and accommodations within the volume.
- NASA needs methods to unobtrusively collect NHV data without impacting crew time.
- Data required includes metrics such as location and orientation of crew, volume used to complete tasks, internal translation paths, flow of work, and task completion times.
- In less constrained environments methods exist yet many are obtrusive and require significant post-processing.
- Examples used in terrestrial settings include infrared (IR) retro-reflective marker based motion capture, GPS sensor tracking, inertial tracking, and multi-camera methods
- Due to constraints of space operations many such methods are infeasible. Inertial tracking systems typically rely upon a gravity vector to normalize sensor readings, and traditional IR systems are large and require extensive calibration.
- However, multiple technologies have not been applied to space operations for these purposes. Two of these include:
  - 3D Radio Frequency Identification Real-Time Localization Systems (3D RFID-RTLS)
  - Depth imaging systems which allow for 3D motion capture and volumetric scanning (such as those using IR-depth cameras like the Microsoft Kinect or Light Detection and Ranging / Light-Radar systems, referred to as LIDAR)

## Overall Approach and Schedule

- The plan of work for this project includes several steps spread across a three year period:
  - Step 1 (2015-2016):** Integration of the hardware technologies involved (3D RFID-RTLS and Kinect) and initial development of software interfaces.
  - Step 2 (2016-2017):** Development and refinement of the system and its interfaces, following best practices in usability and human centered design, finalization of data formats, and conducting engineering pilot tests.
  - Step 3 (2017-2018):** Validation in HERA, delivery of final deliverables, and publication.

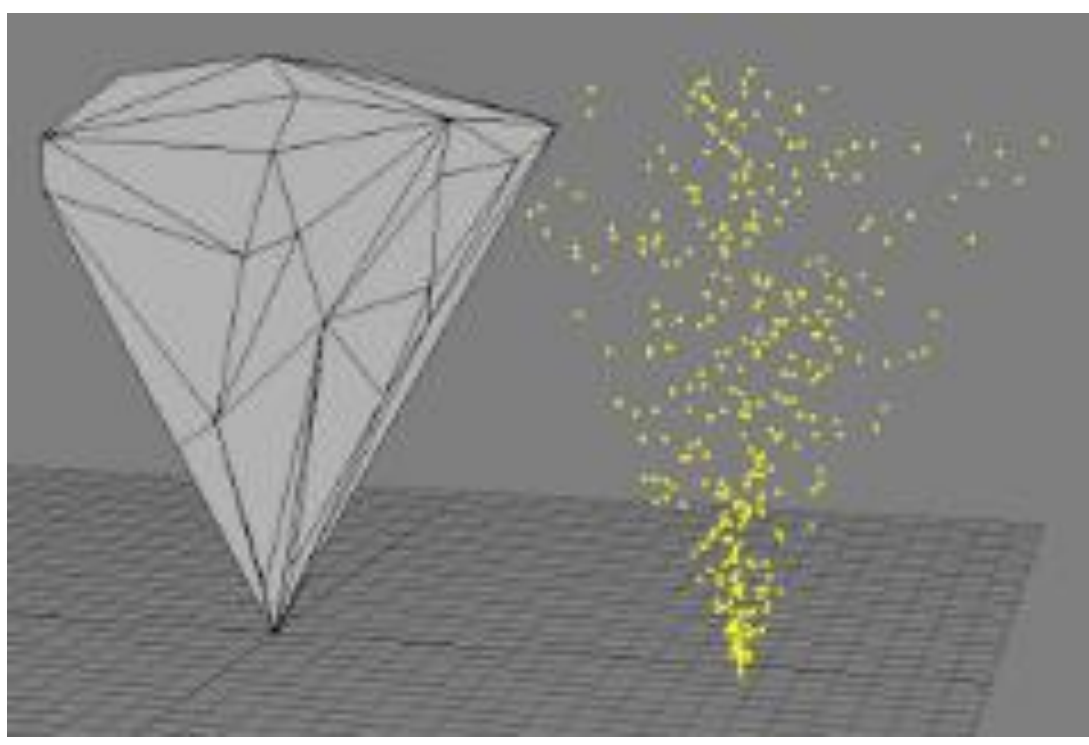
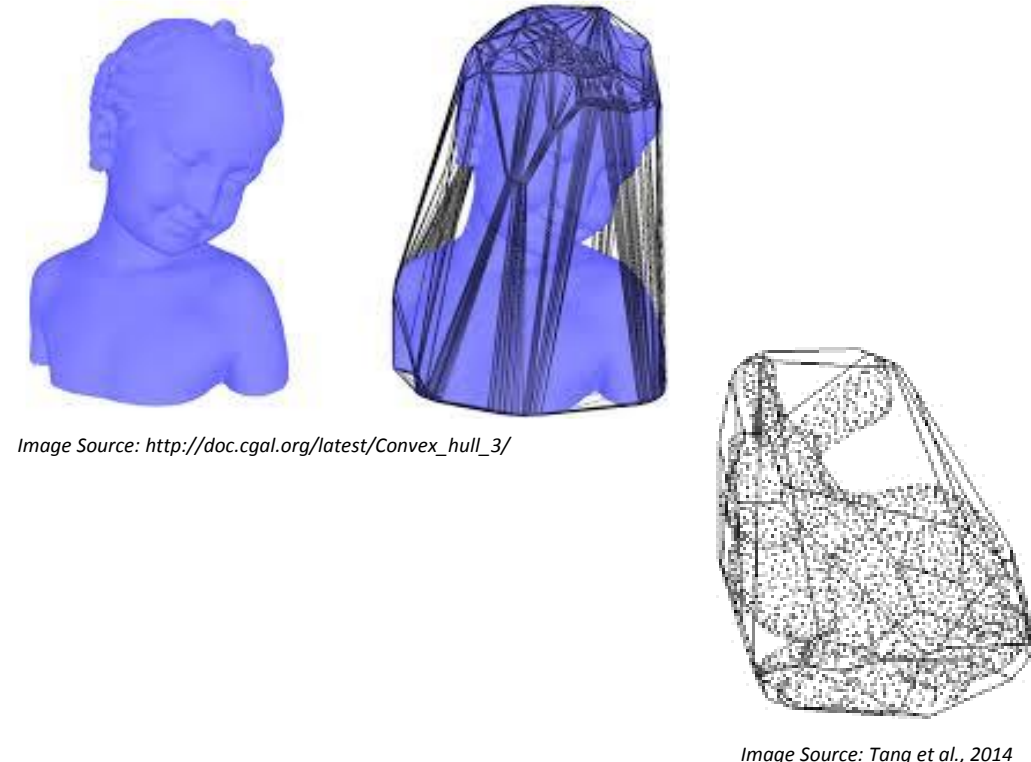
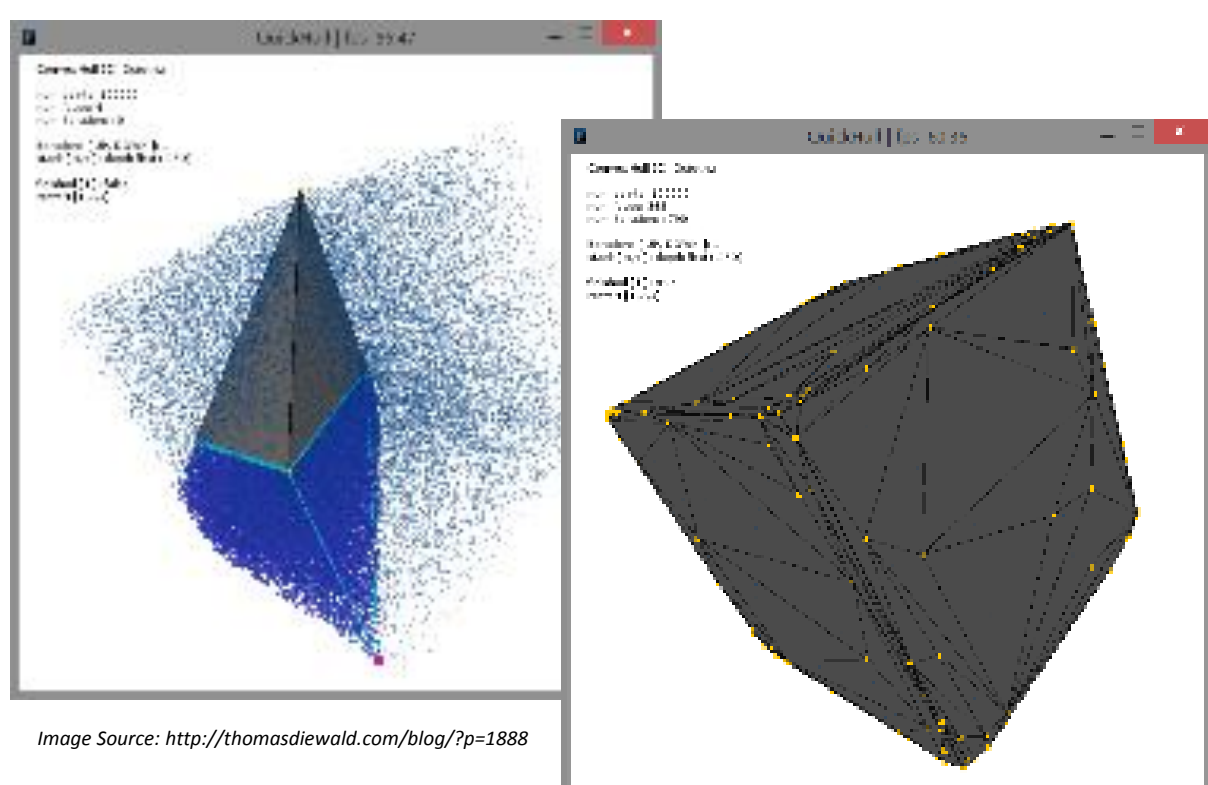
## Algorithms: Joint Data

- Joint tracking performed on body frame data from Kinect.
- Data provided by Kinect sensor at 30 hz in real-time
- Joint angles are being calculated in real-time for all tracked persons
- The output of this process is a biomechanical skeleton structure with body segment position, joint positions, and general biomechanical postural data that compares well with traditional motion capture data (e.g., Vicon)
- Per reviews, accuracy for most joint angles is within 6-13° varying by joint (Fern´andez-Baena et. al, 2012)
- The Kinect’s low cost, marker-less implementation, low physical interference, speed, and ease of use make it valuable for rough posture acquisition, and certainly provides more accuracy and better posture tracking than manual video frame analysis



## Algorithms: Point Cloud Data

- NHV occupied by subjects over time is collected by accumulation of point cloud data from the Kinect, followed by volume calculations over a given period of interest (e.g. per frame or unit time).
- Heat-map generation algorithms allow assessment of co-located operations by multiple subjects in a single environment
- Implementation of convex hull based methods is complete
- Also implemented are Ritter’s algorithm and a rotating caliper based bounding volume, both of which are rapid but over-estimate volume usage.
- Performed more quickly than Kinect Fusion based mesh generation process.
- Once a closed mesh is generated encapsulating the point cloud for a person, it is trivial to calculate volume of the mesh through tetrahedral based volume calculations for each triangle in the mesh from a central point
- Provides NHV assessment in both real-time and time-period perspectives
- Also allows generation of volume data for numerous generic postures when combined with the joint data, and allow for population based distributional assessment of anthropometry impacts to volume



## Objectives

- Develop an automated methodology for collecting space utilization and NHV data::
  - Adapt and integrate two independent technologies, 3D RFID-RTLS and Microsoft Kinect 3D volumetric and anatomical scanning tools, into a single solution,
  - Format the data in such a way that it can be used in computational modeling, and
  - Validate the resulting system and data outcomes against standard measures
- Validation of the system in the Human Exploration Research Analog (HERA)
- Data collected by the system will include:
  - The number of crew present in each area of the vehicle at any given time
  - The quantity of time crew spend at each workstation in the performance of tasks
  - The physical orientation of crew while utilizing the provided volume
  - Frequent or common translation paths and traffic flow patterns within the volume
  - Operational flow/volume required for mission tasks by single or multiple crew
  - 3D biomechanical and postural data related to individual and team based tasks

## System Design

- Ultra-wide band 3D RFID-RTLS system with 4-8 antennas, 4 active tags on each person minimizing occlusion
- Volumetric scanning and biomechanical tracking system utilizing 4-6 Kinect V2 systems to minimize occlusion
- Software design uses a functional design model with a centralized integration and analysis capability.

## Algorithms: 3D RFID-RTLS Data

- Tracking of crew movements is performed in real-time by using active, ultra-wide band (UWB) radio frequency identification (RFID) real-time localization services (RTLS).
- System resolution is +/- 15cm in each of the X, Y, and Z axes of a given environment.
- Refresh rates high as 5hz (decreases battery life) or low as 1x/day (increases battery life).
- Tracking of humans allows for collection of data for industrial engineering time & motion studies/task assessment and process evaluation.
- Humans can wear from 1-4 tags either via Velcro on their clothing or on a vest or strap.
- System will allow collection of such data without crew intervention and can be collated over long periods of time (many hours, days, or months, depending on the interests).
- Tags can also be used for real-time location of stowage items or critical equipment, reducing crew time required for finding materials for task completion.

## Current Status

- All raw data is being collected (biomechanical, point cloud, and 3D RFID-RTLS) and stored
- Currently integrating the multi-Kinect functionality for increased point cloud resolution
- Also implementing a greater number of RFID antennas to reduce occlusions and increase resolution
- Pilot testing anticipated Summer/Fall of 2017

